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MECHANICAL PROPERTIES OF ROCK SAMPLES FROM CHALK RIVER, ONTARIO

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ABSTRACT

As part of a comprehensive mechanical property investigation of rock formations in research areas associated with the Canadian Nuclear Fuel Waste Management Program (NFWMP), CANMET and Ontario Hydro undertook a joint project to study the uniaxial mechanical properties of rock samples from a research area in Chalk River.

The objectives of the study were, to provide data and analysis for the vault design task and input data for geosphere modelling and other tasks.

The properties measured and the respective ranges of values determined for 46 CR-6, 7, 8 and 9 core samples are as follows:

(i)	Uniaxial compressive strength	34 to 298 MPa
(ii)	Young's modulus	53.0 to 145.9 GPa
(iii)	Poisson's ratio	0.13 to 0.41
(iv)	Brazilian tensile strength: load parallel to foliation: load perpendicular to foliation:	14.0 to 25.4 MPa
(v)	Dilatational wave velocity at zero axial load	4.17 to 7.28 km/s

The wide range of values, determined for each of these properties, reflects the lithological variability of the rocks at Chalk River. Based on the Deere and Miller Engineering classification for intact rock, the rock formations at Chalk River fall in the range of medium to very strong rock with medium to high modulus ratio.

PROPERTIES MECHANIQUES D'ECHANTILLONS DE ROCHES DE CHALK RIVER (ONTARIO)

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RÉSUMÉ

Dans le cadre de l'étude globale des propriétés mécaniques de formations auxquelles sintéresse le Programme canadien de gestion des déchets de combustible nucléaire, le CANMET et l'Hydro-Ontario ont entrepris ensemble d'étudier les propriétés mécaniques uniaxiales d'échantillons de roches provenant de la formation RA-2 de Chalk River (Ontario).

Le but de l'étude était d'obtenir des données et de faire des analyses relatives à la conceptiuon de voûtes d'enfouissement et de collecter des données pourant servir à la modélisation de la réosphére ainsi qu'à d'autres tâches.

Les propriétés mesurées et les gams des valeurs déterminées deséchantillons 46 CR-6, CR-7, CR-8 et CR-9 de la formation 2 sont les suivants:

(i)	Résistance à la compression uniaxiale	de 181 à 287 MPa
(ii)	Module de Younge	de 53,0 à 145,9 GPa
(iii)	Ratio de Poisson	de 0,13 à 41

(iv)	Résistance à la traction brésilienne	
	Charge paralléle à la foliation	de 14,0 à 25,4 MPa
(v)	Vitesse de l'onde de dilatation sous	
	charge axiale nulle	de 4,17 à 7,28 km/s

L'étude de la gamme des valeurs reflète la variabilité lithologique de la formation de Chalk River. D'aprés la classification de Deere and Miller pour roches intactes, la formation de Chalk River appartient à la catégorie des roches de moyenne à grande résistance et à ratio de module moyen à élevé.

INTRODUCTION

Mechanical rock properties provide essential rock characterization data on a geological formation required for engineering and other geomechanics applications.

As part of a comprehensive program, CANMET and Ontario Hydro carried out a joint project to study the uniaxial mechanical properties of rock formations located at Atikokan, Pinawa and Chalk River Research areas. This was to characterize rock for the Canadian Nuclear Fuel Waste Management Program (NFWMP) and to evaluate the potential suitability of the rock reserves for nuclear waste disposal. The studies were undertaken to provide data and analysis for vault design and geosphere modelling, as well as to assist other activities and tasks. Measurements carried out included: uniaxial compressive strength, Brazilian Tensile strength,and Compressive wave velocity tests.

The following properties were determined:

(i) Bulk Density

(ii) Uniaxial compressive strength

(iii) Young's modulus

(iv) Poissons's ratio

(v) Brazilian tensile strength

(vi) Dilatational (P-) wave velocity

The objectives of this report are:

1. to provide a summary of the uniaxial elastic properties data which have been compiled to date on rock samples from the Chalk River research area (RA-2) within the Energy, Mines and Resources (EMR) Rock Property Activity;
2. to fulfill geosphere modelling requirements by providing some information on the methodology used to carry out the measurements, and to compare the test results to published generic rock properties data.

GEOLOGICAL DESCRIPTION OF CORE SAMPLES

The specimens used for the study consisted of "R" series standard samples from boreholes CR-6, CR-7, CR-8 and CR-9 at Research Area (RA-2) near Chalk River, Ontario. Standard sample selection within EMR's Rock Property Activity is governed by a set of criteria (Larocque, 1978); samples are distributed as shown in Fig. 1. The standard samples are generally selected to reflect the generalized lithology intersected in each borehole at a research area, and are considered to be representative of the rock formation in the immediate vicinity of the borehole.

The rock specimens are identified according to the depth along the borehole in which they were taken, in metres, as shown in Table 1 to 4.

Detailed geological core log descriptions of the specimens are given in Chernis et al. (1979 a, b), and Katsube et al. (1978, 1979). In addition, results of detailed microscopic examinations of specimens taken from P and/or Q series of the RA-2 Standards Samples are summarized in reports by Chernis (1979 a,b); Nuyens (1980); and Hamilton (1983).

Standard samples used for investigations were all metamorphic rocks that commonly had a gneissic structure, and were either banded, layered or foliated. On the basis of minerology, the rock can be classified into ten rock types using Streckeisen's Scheme of Classification (1967) for plutonic rocks. The total number of samples and the rock types tested based on the above classification are as follows:

(a) 5 Granitic gneiss
(b) 1 Grandoioritic gneiss
(c) 6 Quartz monzonitic gneiss
(e) 9 Monzonitic gneiss
(f) 1 Meta-dioritic gneiss
(g) 2 Meta-gabbroic gneiss
(h) 4 Diabase
(i) 1 Amphibolite
(j) 1 Pegmatite.
(k) 18 Quartz monzodioritic gneiss

DESCRIPTION OF MEASUREMENTS

Sample preparation and testing were carried out to conform as closely as possible with the American Society for Testing and Materials (ASTM) Standards (ASTM, 1971, 1979) and CANMET's Pit Slope Manual specifications (Gyenge and Herget, 1977).

SAMPLE PREPARATION

Cylindrical test specimens with length diameter ratio between 2.0 and 2.2 were used for the uniaxial compression and dilatational wave velocity measurements. With regards to the Brazilian tensile strength tests, discs with thickness to diameter ratio of about 1:2 were used.

Test samples were cut slightly larger than their final dimensions using a water-cooled diamond-saw. Specimen ends were then ground to within 0.03 mm of being parallel to each other, and at right angles to the longitudinal axis. Hardened steel jigs and a lapping wheel were used for this purpose.

The specimens were tested in a dry state after surface air drying in the laboratory.

To carry out elastic deformation measurments, strain gauges, oriented to measure axial and circumferential strains, were centered equidistant from the two ends of the specimen. Gauges of similar orientations were located on the opposite sides of the specimen. The axial and circumferential gauges were connected in series to form single active-gauges. These were used in half bridge configuration for strain measurements. The gauges used were of the BLH Electronics Co. SR-4, FAE Series.

EQUIPMENT AND TESTING PROCEDURE

Dilatational Wave Velocity Measurements

Axial dilatational velocity measurements were carried out on samples already gauged for elastic deformation measurement.

The testing equipment consisted of: transmitting and receiving specimen platens containing piezoelectric transducers, a high voltage pulse generator, a signal amplifier, and a Tektronix Type 555 dual-beam oscilloscope with delay sweep and time base resolution to 0.1 micro-second per centimeter.

The velocity equipment was used with a 1.33 MN hydraulic press (Tinius Olsen Universal Testing Machine) to measure specimen dilatational wave transit time as a function of applied axial load.

The samples and transducer assembly were placed between the platens of the hydraulic press and were axially stressed in increments of about 2.7 MPa to a maximum stress level. Due to structural limitations of the transducer platens, maximum applied stresses were 29 MPa for CR-8 and CR-9 samples and 43 MPa for CR-6 and CR-7 samples. At each incremental stress level, the transmitter piezoelectric transducer excited by a pulse generator was used to send stress waves into the specimen. These were detected by the receiver piezoelectric transducer. The sweep of the oscilloscope, which was triggered at the onset of each generated pulse, was used to display the seismic disturbance detected by the receiver piezoelectric platen.

The measured delayed arrival time of the seismic disturbance, the specimen length, and measured zero delay of the sonic system were used to determine specimen dilatational velocity.

Prior to individual specimen time delay measurements, the transmitting and receiving platens were placed together and the zero delay time of the sonic system was determined. Delay time was measured to 0.01 micro-second, (Annor et al, 1979; Gyenge and Herget, 1977).

Data Treatment

Dilatational velocity (V_p) of a specimen was determined from the relationship:

$$V_p = L/(tp - to) \qquad \text{Eq 1}$$

where L = specimen length (m)
tp = time of transit (s)
to = zero delay time of the sonic system(s).

UNIAXIAL COMPRESSION MEASURMENTS

CR-6 and CR-7 Specimens

The equipment used to measure axial and circumferential specimen deformation under applied axial load consisted of two Phillips PR9302 Strain

bridges and a Mosleley Autograph 2FRA X-Y recorder. The bridges were used in a half bridge configuration. Axial and circumferential strain gauges were used to provide voltage analog outputs of the axial and circumferential strains produced in the sample by axial loading. These analogs were used to drive the two Y-axis plotters of the 2FRA-X-Y recorder independently. Axial and circumferential stress strain curves were obtained in this manner for each of the CR-6 and CR-7 specimens tested. The curves were used to determine Young's modulus and Poissons's ratio. The axial load was increased until failure occurred and the failure load noted. Recorder outputs of the axial stress versus strain curves are provided in Annor and Geller (1979).

CR-8 and CR-9 Specimens

A method similar to that described above was used for carrying out the uniaxial compression measurements of the CR-8 and CR-9 specimens. Each specimen, however, was subjected to the three loading and unloading cycles to compensate for the effects of stress relaxation due to drilling. Reported Young's modulus and Poisson's ratio were determined from the average value of the final two-loading and unloading cycles (McKay, 1980). Recorder output of the stress versus strain curves are reported in McKay (1980).

Data Treatment

Young's modulus was calculated for each specimen by determining the value of the tangent to the axial strain curve at 50% of failure load. The ratio of the tangent to the transverse strain curve to the tangent of the axial strain curve at the 50% failure load, was used to determine the specimen's Poisson's ratio. The ultimate compressive strength of each specimen was calculated by dividing the specimen failure load by specimen cross sectional area.

Brazilian Tensile Strength Tests

Specimens were tested according to ASTM specification C496-71. Test specimens were loaded diametrically between two hardened steel platens in a hydraulic press. Load was applied until the specimen failed.

Data Treatment

The tensile strength of a specimen was determined from the relationship:

$$\sigma_t = 2P/\pi Dt \qquad \text{Eq 2}$$

where σ_t = specimen tensile strength (MPa)
P = failure load (Newton)
D = diameter of disc (m)
t = thickness of disc (m).

DATA ANALYSIS AND RESULTS

Basic data for the measurements described above are provided in the following CANMET and Ontario Hydro Technical Reports: Annor and Geller (1978 a,b) and McKay (1980). Borehole vertical depth and elevations for each specimen were estimated from Geological Survey of Canada Directional Survey Reports on Cr-6, CR-7, CR-8 and CR-9 (Dugal, 1983).

DATA SUMMARY

The test results, in terms of boreholes are compiled in Tables 1 to 6. Tables 7 and 8 summarize the range, mean and standard deviation values of specimen bulk density, uniaxial compressive strength, tangent modulus of elasticity, Poisson's ratio, zero pressure compressive wave velocity and Brazilian Tensile strength, based on rock type.

Depth profiles of uniaxial compressive strength, zero pressure compressive wave velocity, tangent modulus of elasticity, and Poisson's ratio are provided in Figs. 2 to 5 in terms of boreholes.

Figure 6 shows a relationship between Young's modulus and compressive strength for the Chalk River rock specimens based on the Deere and Miller Classification for Intact Rock (1966). Modulus ratio for this classification is defined as follows:

$$\text{Modulus ratio} = \frac{\text{tangential Young's modulus at 50\% ultimate strength}}{\text{uniaxial compressive strength}}$$

and is interpreted as follows:

high modulus ratio	>500
medium modulus ratio	200 < modulus ratio <500
low modulus ratio	<200

Statistical distribution of calculated properties, in terms of sample population, and presented as histrograms are also provided in Figs. 7 to 12.

DISCUSSIONS

The test results indicate that the rocks at Chalk River have variable properties in terms of uniaxial compressive strength, Young's modulus, Poisson's ratio, zero pressure compressive wave velocity, and Brazilian tensile strength. Therefore, in terms of geomechanical characterization, the rock mass must be regarded as heterogeneous. This variability in mechanical properties is to be expected for metamorphic formations, especially for those compsed of a variety of lithologies, such as those found at the Chalk River research area (Tables 1-6).

The tested specimens were predominantly gneissic in character (87%), and were classified into the following compositional sub-groups according to Streckeisen's (1967) scheme of classification for plutonic rocks: quartz-monzonitic, quartz-monzodioritic, granitic, meta-gabbroic, and meta-dioritic gneiss. There were also, diabase (11%), and other rock types (2%), among the tested specimens.

To fulfill engineering design data requirements for metamorphic formations it is generally essential that the strength and deformational anisotropy be determined. The wide variability of the test data suggests the need to evaluate the strength and deformational anisotropy of the Chalk River formation.

Because of the variable orientation of the core samples which were based on drillhole directions, however, testing for anisotropy of the mechanical properties was not possible.

In terms of engineering classification for intact rock by Deere and Miller, (1966), the Chalk River formation falls into the range of medium to very strong rock with medium to very high modulus ratio (Fig. 6).

With regards to scaling factors between in situ rock mass strength, and laboratory-determined small scale properties Hoek and Brown (1980), suggest the following approximate empirical relationship between uniaxial compressive strength (Qu), and specimen diameter (d), (for specimen diameters between 10 and 200 mm) for unjointed intact rock:

$$Qu = Qu_{50} \, (50/d)^{0.18} \qquad \text{Eq 3}$$

where Qu_{50} = the uniaxial compressive strength of a specimen of 50 mm diameter

and d = diameter of the specimen in mm.

In the case of a jointed rockmass Hoek and Brown (1980) suggest that strength variation be related to discontinuity spacing.

Some of the factors to be taken into consideration when comparing these test results and literature referenced-data should include the procedures followed and the conditions of samples used to develop the literature reported data. Sometimes that information is omitted from the referenced literature. The test results however, compare favourably with reported uniaxial compressive strength and deformation data for rocks of similar mineral composition as those of the Chalk River formation (Touloukian et. al. 1981).

A generalized relationship between field and laboratory determined Young's modulus has been proposed by Hauze (1980). The relationship, was determined from a literature review of large geotechnical projects and is expressed as follows:

$$0.2 < E_f/El < 0.60 \qquad \text{Eq 4}$$

where: E_f and El, refer to Young's moduli determined in the field, and laboratory, respectively.

Based on equation 4 the estimated Young's modulus for the rock mass at Chalk River can be expected to vary between 10 and 90 GPa. This wide range of Young's modulus values are in agreement with those found in the published literature when factors such as moisture and fractures are considered (Touloukian et. al. 1981, Vutukuri et. al. 1974).

In order to obtain a comprehensive engineering design data for the rock mass at Chalk River, it is recommended that other tests, such as triaxial compression, and in situ strength and deformational measurements, be carried out.

CONCLUSIONS

The test results indicated that, rock strength, deformational properties, and compressive wave velocity data were in accordance with the lithological variability of the Chalk River formation.

In general, the test results compare favourably with data in the published literature, for rocks of similar mineralogical compositions as the Chalk River formation.

Additional mechanical property tests, such as triaxial compression, in situ strength and deformation measurements, etc., are required for a comprehensive development of engineering design data for the Chalk River formation.

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Table 1 - Summary of uniaxial elastic properties and dilatational velocity data for borehole CR-6 specimens

Specimen identification	Borehole characteristics		Specimen characteristics	Compressive strength	Tangent modulus	Poisson's ratio	Dilatational velocity		Rock type
	Vertical depth (m)	Elevation[a] (m)	Density (gm/m^3)	(MPa)	(GPa)		V_o at 0.1 MPa (Km/s)	V_p at 43 MPa (Km/s)	
CR-6 43.90	42.8	102.6	2.70	192	73	0.26	4.8	5.66	Quartz Monzodioritic Gneiss
CR-6 87.70	84.3	61.1	3.09	280	104	0.23	6.4	6.48	Monzonitic Gneiss
CR-6 93.40	90.3	55.1	2.75	202	66	0.25	4.8	5.57	Quartz Monzodioritic Gneiss
CR-6 143.70	138.3	7.1	2.74	226	71	0.28	5.3	6.04	Monzonitic Gneiss
CR-6 166.30	160.1	-14.7	2.76	220	74	0.27	5.4	6.01	Monzonitic Gneiss
CR-6 193.65	186.6	-41.2	2.66	179	68	0.25	5.2	5.70	Granitic Gneiss
CR-6 227.20	218.9	-73.5	3.00	216	93	0.27	6.2	6.27	Diabase
CR-6 237.20	228.0	-82.6	2.97	287	92	0.29	6.2	6.39	Diabase
CR-6 245.265[a]	236.2	-90.8	2.57	34			2.6		Diabase (Heavily Altered)
CR-6 286.30	275.1	-129.7	3.02	209	108	0.29	6.6	6.65	Diabase
CR-6 301.50	290.3	-144.9	2.74	212	73	0.26	5.8	6.08	Quartz Monzodioritic Gneiss
Mean			2.84	222	82	0.27	5.7	6.10	
Std. Dev.			0.16	35	16	0.02	0.7	0.34	

[a]Elevations are with respect to sea level.

[a]Data excluded from mean and standard deviation calculations.

Table 2 - Summary of uniaxial elastic properties and dilatational velocity data for borehole CR-7 specimens

Specimen identification		Borehole characteristics		Specimen characteristics	Compressive strength	Tangent modulus	Poisson's ratio	Dilatational velocity		Rock type
		Vertical depth (m)	Elevation* (m)	Density (gm/m^3)	(MPa)	(GPa)		V_o at 0.1 MPa (Km/s)	V_p at 43 MPa (Km/s)	
CR-7	11.10	10.6	132.6	2.69	171	58	0.23	4.6	5.70	Granodioritic Gneiss
CR-7	26.00	25.1	118.2	2.70	188	67	0.27	5.0	5.74	Quartz Monzonitic Gneiss
CR-7	69.90	65.5	77.8	2.78	188	63	0.22	5.2	5.68	Quartz Monzodioritic Gneiss
CR-7	81.10	78.3	65.0	2.67	248	63	0.24	4.7	5.65	Monzonitic Gneiss
CR-7	104.90	101.3	42.0	2.67	195	67	0.26	5.2	5.77	Quartz Monzodioritic Gneiss
CR-7	132.00	127.6	15.9	2.73	219	75	0.29	6.0	6.06	Quartz Monzodioritic Gneiss
Mean				2.71	202	66	0.25	5.1	5.77	
Std. Dev.				0.04	28	6	0.02	0.5	0.15	

*Elevations are with respect to sea level.

Table 3 - Summary of uniaxial elastic properties and dilatational velocity data for borehole CR-8 specimens

Specimen identification	Borehole characteristics		Specimen characteristics	Compressive strength	Tangent modulus	Poisson's ratio	+ Dilatational velocity		Rock type
	Vertical depth (m)	Elevation* (m)	Density (gm/m^3)	(MPa)	(GPa)		V_o at 0.1 MPa (Km/s)	V_p at 43 MPa (Km/s)	
CR-8 28.50	27.6	111.0	2.68	117	53.0	0.26	4.17	5.60	Quartz Monzodioritic Gneiss
CR-8 43.70	42.3	96.3	2.75	188	64.4	0.25	5.19	6.01	Quartz Monzodioritic Gneiss
CR-8 50.00	48.7	89.9	2.69	155	57.3	0.23	4.60	5.68	Granitic Gneiss
CR-8 54.30	52.5	86.1	2.73	203	62.1	0.20	4.92	5.99	Quartz Monzodioritic Gneiss
CR-8 83.10	80.4	58.2	2.75	177	66.4	0.21	5.42	6.01	Quartz Monzodioritic Gneiss
CR-8 144.60	138.0	0.6		116	61.2	0.24			Quartz Monzodioritic Gneiss
CR-8 144.80	139.0	-0.4	2.80	125	57.2	0.42	5.11	5.96	Quartz Monzodioritic Gneiss
CR-8 185.60	178.1	-39.5	2.75	235	66.7	0.20	4.92	6.02	Granitic Gneiss
CR-8 214.80	206.5	-67.9	2.60		70.3	0.28			Pegmatite
CR-8 219.20	210.4	-71.8	2.65	154	63.4	0.21	4.84	5.99	Granitic Gneiss
CR-8 267.60	256.2	-117.6	2.95	81	59.8	0.13			Amphibolite
CR-8 305.32	291.5	-152.9	2.67	209	66.4	0.20	4.86	6.06	Granitic Gneiss
Mean			2.73	160	62.4	0.24	4.89	5.92	
Std. Dev.			0.04	47	4.9	0.07	0.36	0.16	

+Basic data was provided by Ontario Hydro (McKay, 1980).

*Elevations are with respect to sea level.

Table 4 - Summary of uniaxial elastic properties and dilatational velocity data for borehole CR-9 specimens

Specimen identification	Borehole characteristics		Specimen characteristics	Compressive strength	Tangent modulus	Poisson's ratio	+ Dilatational velocity		Rock type
	Vertical depth (m)	Elevation* (m)	Density (gm/m^3)	(MPa)	(GPa)		V_o at 0.1 MPa (Km/s)	V_p at 43 MPa (Km/s)	
CR-9 18.20	15.1	110.3	2.92	222	102.8	0.27	6.93	6.93	Monzonitic Gneiss
CR-9 69.40	59.3	66.1	2.64	193	90.4	0.22	4.90	5.64	Quartz Monzonitic Gneiss
CR-9 80.00	69.1	56.3	2.75	212	97.6	0.26	5.84	6.13	Quartz Monzonitic Gneiss
CR-9 120.50	103.5	21.9	2.99	133	102.5	0.27	6.68	6.68	Meta-dioritic Gneiss
CR-9 166.50	142.6	-17.3	2.62	259	81.0	0.23	4.51	5.47	Quartz Monzonitic Gneiss
CR-9 207.80	178.1	-52.8	2.73	159	83.1	0.24	5.53	6.15	Quartz Monzodioritic Gneiss
CR-9 265.60	226.7	-101.4		163	81.8	0.20	5.02	5.95	Quartz Monzodioritic Gneiss
CR-9 303.70	258.6	-133.3	2.73	185	79.0	0.26	5.22	5.77	Quartz Monzodioritic Gneiss
CR-9 313.70	266.9	-141.6	2.65	233	76.4	0.24	4.90	5.61	Quartz Monzodioritic Gneiss
CR-9 377.10	318.7	-193.4	2.76	211	79.0	0.28	5.54	5.83	Quartz Monzonitic Gneiss
CR-9 419.20	353.4	-228.1	2.77	146	81.8	0.25	5.78	6.25	Quartz Monzonitic Gneiss
CR-9 480.50	401.9	-276.6	2.78	229	81.0	0.23	5.79	5.79	Monzonitic Gneiss
CR-9 513.60	427.7	-302.4	2.92	107	94.7	0.30	6.40	6.68	Monzonitic Gneiss
CR-9 531.20	441.8	-316.5	2.79	172	86.7	0.19	5.90	6.08	Monzonitic Gneiss
CR-9 566.80	468.4	-343.1	3.11	111	145.9	0.33	7.26	7.28	Monzonitic Gneiss
CR-9 592.90	488.4	-363.1	3.14	175	101.0	0.28	5.33	5.89	Meta-gabbroic Gneiss
CR-9 643.90	524.1	-398.8	3.13	122	103.8	0.27	5.85	6.44	Meta-gabbroic Gneiss
CR-9 682.30	553.4	-428.1	2.83	190	84.6	0.26	6.19	6.40	Quartz Monzodioritic Gneiss
CR-9 701.60	567.7	-442.4	2.78	185	81.6	0.28	4.70	5.28	Quartz Monzodioritic Gneiss
Mean			2.84	179	91.3	0.26	5.70	6.13	
Std. Dev.			0.16	43	16.1	0.03	0.76	0.51	

*Elevations are with respect to sea level.

+Basic data was provided by Ontario Hydro (McKay, 1980).

Table 5 - Summary of Brazilian tensile strength data for borehole CR-8 specimens

Sample identification	Brazilian tensile strength (MPa) + Load parallel to structure	Load perpendicular to structure	Rock type
CR-8 28.3		15.56	Quartz Monzodioritic Gneiss
CR-8 43.6	12.83	16.67	Quartz Monzodioritic Gneiss
CR-8 50.5	15.75	15.77	Granitic Gneiss
CR-8 54.6	15.45	17.04	Quartz Monzodioritic Gneiss
CR-8 83.4	15.09	17.87	Quartz Monzodioritic Gneiss
CR-8 185.5	16.35	18.52	Granitic Gneiss
CR-8 219.5	14.33	16.60	Granitic Gneiss
CR-8 267.7	13.97	15.90	Amphibolite
Mean	14.82	16.74	
Std. Dev.	1.20	1.04	

+Basic data was provided by Ontario Hydro (McKay, 1980).

Table 6 - Summary of Brazilian tensile strength data for borehole CR-9 specimens

Sample identification	Brazilian tensile strength (MPa) + Load parallel to structure	Load perpendicular to structure	Rock type
CR-9 69.61	13.84		Quartz Monzonitic Gneiss
CR-9 80.40	17.97	15.35	Quartz Monzonitic Gneiss
CR-9 120.40	23.55	25.37	Meta-dioritic Gneiss
CR-9 166.30	17.14	16.82	Quartz Monzonitic Gneiss
CR-9 208.00	14.49		Quartz Monzodioritic Gneiss
CR-9 265.10	16.04		Quartz Monzodioritic Gneiss
CR-9 303.95	17.90	15.99	Quartz Monzodioritic Gneiss
CR-9 314.10	15.85	14.26	Quartz Monzodioritic Gneiss
CR-9 377.00	14.02	15.17	Quartz Monzonitic Gneiss
CR-9 419.40	16.08	15.95	Quartz Monzonitic Gneiss
CR-9 531.90	19.68	19.95	Monzonitic Gneiss
CR-9 563.10	21.96	20.62	Monzonitic Gneiss
CR-9 593.10	15.60	14.60	Meta-gabbroic Gneiss
CR-9 646.10	15.84	17.16	Meta-gabbroic Gneiss
CR-9 682.80		13.98	Quartz Monzodioritic Gneiss
Mean	17.14	17.06	
Std. Dev.	2.88	3.35	

+Basic data was provided by Ontario Hydro (McKay, 1980).

Table 7 - Statistical summary of mechanical properties data for various rock types from Chalk River

Borehole identification	Principal rock types		Density (gm/m^3)	Compressive strength (MPa)	Tangent modulus (GPa)	Poisson's ratio	P-wave velocity at 0.1 MPa (Km/s)	Brazilian tensile strength (MPa)	
								Load parallel to structure	Load perpendicular to structure
Chalk River	Gneiss Diabase Pegmatite	*No. values	46	46	47	47	44	21	20
CR-6, 7, 8, 9	Amphibolite	Range	2.56 to 3.14	81 to 287	53.0 to 145.9	0.13 to 0.42	4.17 to 7.28	12.83 to 23.55	13.98 to 25.37
		Mean	2.79	187	78.7	0.25	5.45	16.37	16.96
		Std. Dev.	0.15	45	17.9	0.04	0.71	2.66	2.62
		No values	40	42	42	42	41	20	19
		Range	2.62 to 3.14	107 to 259	53 to 145.9	0.19 to .42	4.17 to 7.28	12.83 to 23.55	13.98 to 25.37
CR-6, 7, 8, 9	Gneiss	Mean	2.78	168	78.0	0.25	5.38	16.48	17.01
		Std. Dev.	0.14	41	17.8	0.04	0.69	2.67	2.68

*No. of values: represents number of data points used for the statistical analysis.

Table 8 - Statistical summary of mechanical properties data for various rock types from Chalk River

Borehole identification	Principal rock types		Density (gm/m^3)	Compressive strength (MPa)	Tangent modulus (GPa)	Poisson's ratio	P-wave velocity at 0.1 MPa (Km/s)	Brazilian tensile strength (MPa)	
								Load parallel to structure	Load perpendicular to structure
CR-6, 7, 8, 9	Quartz Monzodioritic Gneiss	*No. values	16	18	18	18	17	7	7
		Range	2.65 to 2.83	116 to 233	53.0 to 84.6	0.20 to 0.42	4.17 to 6.19	12.83 to 17.90	13.98 to 17.87
		Mean	2.74	262	70.4	0.26	5.19	15.38	15.91
		Std. Dev.	0.05	34	9.5	0.05	0.50	1.55	1.43
CR-7, 8, 9	Quartz Monzonitic Gneiss	No values	6	6	6	6	6	5	4
		Range	2.62 to 2.77	146 to 259	67 to 97.6	0.22 to 0.28	4.51 to 5.84	13.84 to 17.47	15.17 to 16.82
		Mean	2.71	202	82.8	0.25	5.26	15.81	15.82
		Std. Dev.	0.06	37	10.4	0.02	0.54	1.84	0.74

*No. of values: represents number of data points used for the statistical analysis.

Table 8 - Cont'd

Borehole identification	Principal rock types		Density (Mg/m^3)	Compressive strength (MPa)	Tangent modulus (GPa)	Poisson's ratio	P-wave velocity at 0.1 MPa (Km/s)	Brazilian tensile strength (MPa)	
								Load parallel to structure	Load perpendicular to structure
		*No. values	1	1	1	1	1	1	1
CR-9	Meta-dioritic Gneiss	Range	2.99	133	102.5	0.27	6.68	23.55	25.37
		Std. Dev.							
		No values	2	2	2	2	2	2	2
		Range	3.14 and 3.13	122 and 175	101.0 and 103.8	0.28 and 0.27	5.33 and 5.85	15.60 and 15.84	14.60 and 17.16
CR-9	Meta-gabbroic Gneiss	Mean	3.14	149	102.4	0.28	5.59	15.72	15.88
		Std. Dev.	0.01	37	2.0	0.01	0.37	0.17	0.81

*No. of values: represents number of data points used for the statistical analysis.

Table 8 - Cont'd

Borehole identification	Principal rock types		Density (gm/m^3)	Compressive strength (MPa)	Tangent modulus (GPa)	Poisson's ratio	P-wave velocity at 0.1 MPa (Km/s)	Brazilian tensile strength (MPa)	
								Load parallel to structure	Load perpendicular to structure
		*No. values	1	1	1	1	1		
CR-7	Grandior-itic Gneiss	Range	2.69	171	58	0.23	4.6		
		Mean							
		Std. Dev.							
		No values	5	5	5	5	5	3	3
CR-6, 8	Granitic Gneiss	Range	2.65 to 2.75	154 to 235	57.3 to 58	0.20 to 0.25	4.60 to 5.20	14.33 to 16.35	15.77 to 10.52
		Mean	2.68	186		0.22	4.88	15.48	16.96
		Std. Dev.	0.04	34	4.3	0.02	0.22	1.04	1.41

*No. of values: represents number of data points used for the statistical analysis.

Table 8 - Cont'd

Borehole identification	Principal rock types		Density (gm/m^3)	Compressive strength (MPa)	Tangent modulus (GPa)	Poisson's ratio	P-wave velocity at 0.1 MPa (Km/s)	Brazilian tensile strength (MPa)	
								Load parallel to structure	Load perpendicular to structure
		No. values	9	9	9	9	9	2	2
		Range	2.67 to 3.11	107 to 280	63 to 145.9	0.19 to 0.33	4.70 to 7.28	19.68 and 21.96	19.95 and 20.62
CR-6, 7, 9	Monzonitic Gneiss	Mean	2.86	202	91.5	0.26	6.01	20.82	20.29
		Std. Dev.	0.156	50	24.8	0.04	0.82	1.61	0.47
		No values	1	1	1	1	0	1	1
		Range	2.95	81	59.8	0.13	-	13.97	15.90
CR-8	Amphibolite	Mean							
		Std. Dev.							

Table 8 - Cont'd

Borehole identification	Principal rock types		Density (gm/m^3)	Compressive strength (MPa)	Tangent modulus (GPa)	Poisson's ratio	P-wave velocity at 0.1 MPa (Km/s)
CR-6	Diabase	No. values	3	3	3	3	3
		Range	2.97 to 3.02	209 to 287	92 to 108	0.27 to 0.29	6.2 to 6.6
		Mean	3.00	237	97.7	0.28	6.33
		Std. Dev.	0.02	43	9.0	0.012	0.23
CR-8	Pegmatite	No values	1		1	1	
		Range	2.60		70.3	0.28	
		Mean					
		Std. Dev.					

LEGEND

EPB - The Earth Physics Branch, Energy, Mines and Resources, Canada.

GSC - Geological Surveys of Canada.

CNT - (CANMET), Canada Centre for Mineral and Energy Technology.

AECL - Atomic Energy of Canada Limited.

ROCK PROPERTY ACTIVITY; STANDARD SAMPLE DISTRIBUTION SCHEME (1979/80)

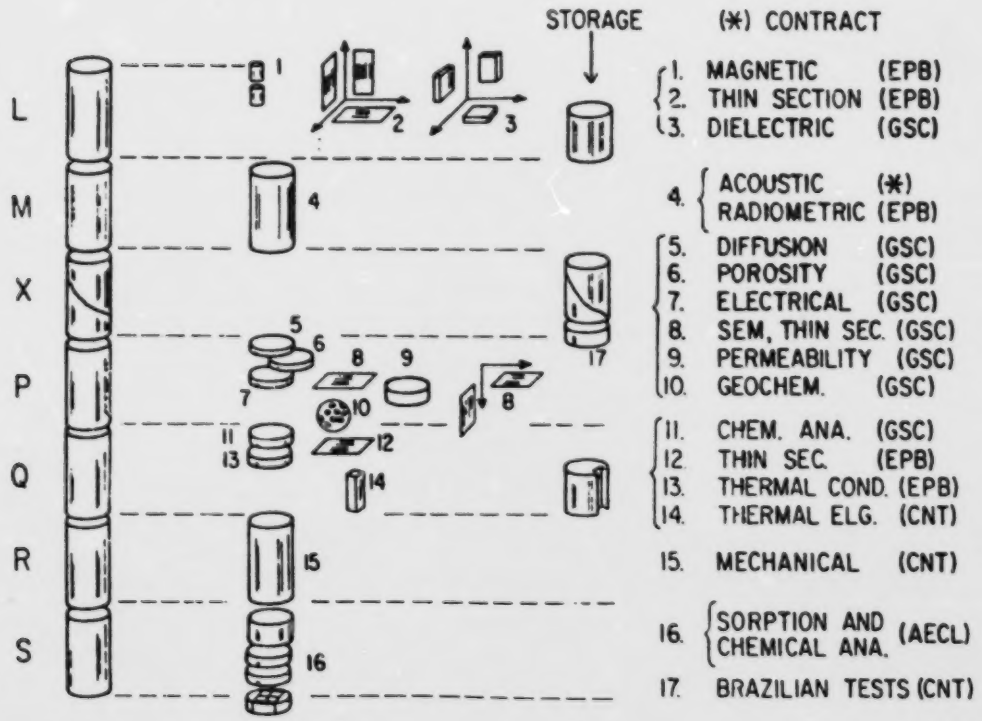


Fig. 1 - Standard sample

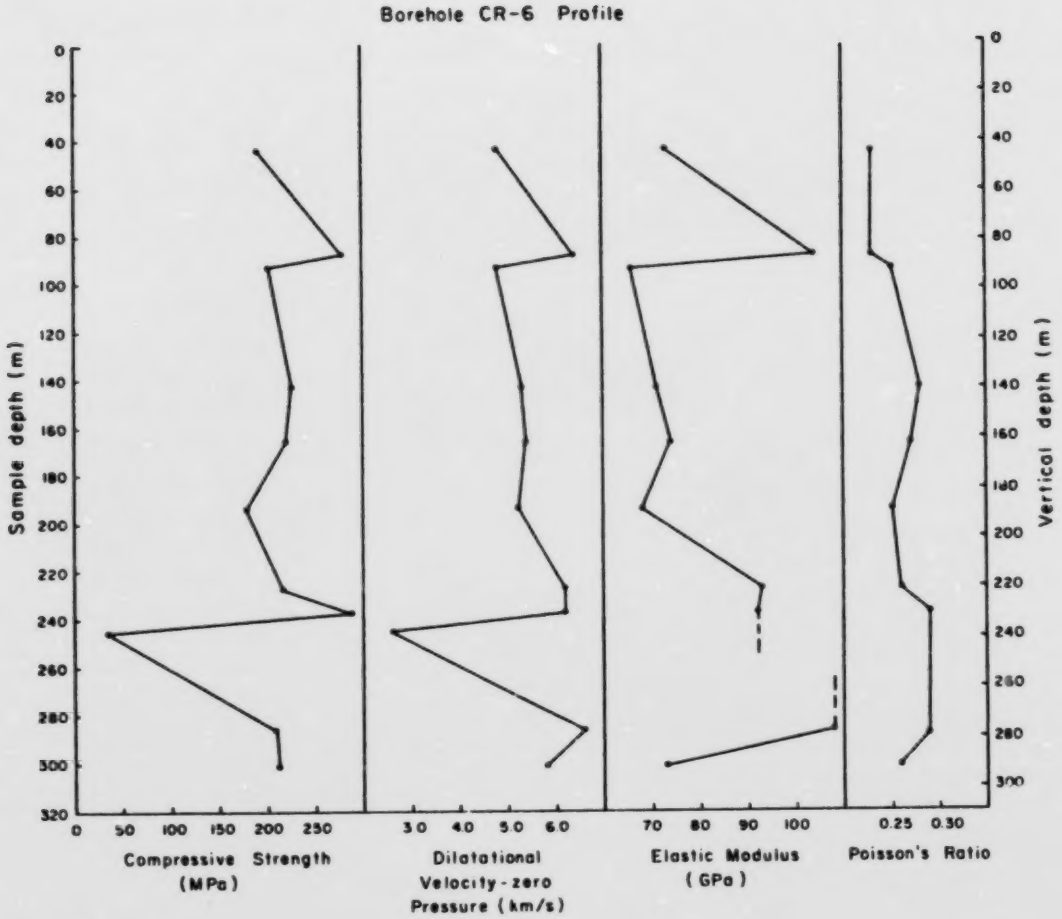


Fig. 2 - Uniaxial elastic properties and dilatational wave velocity profiles for borehole CR-6.

*Sample depth refers to the distance from the surface along borehole length.

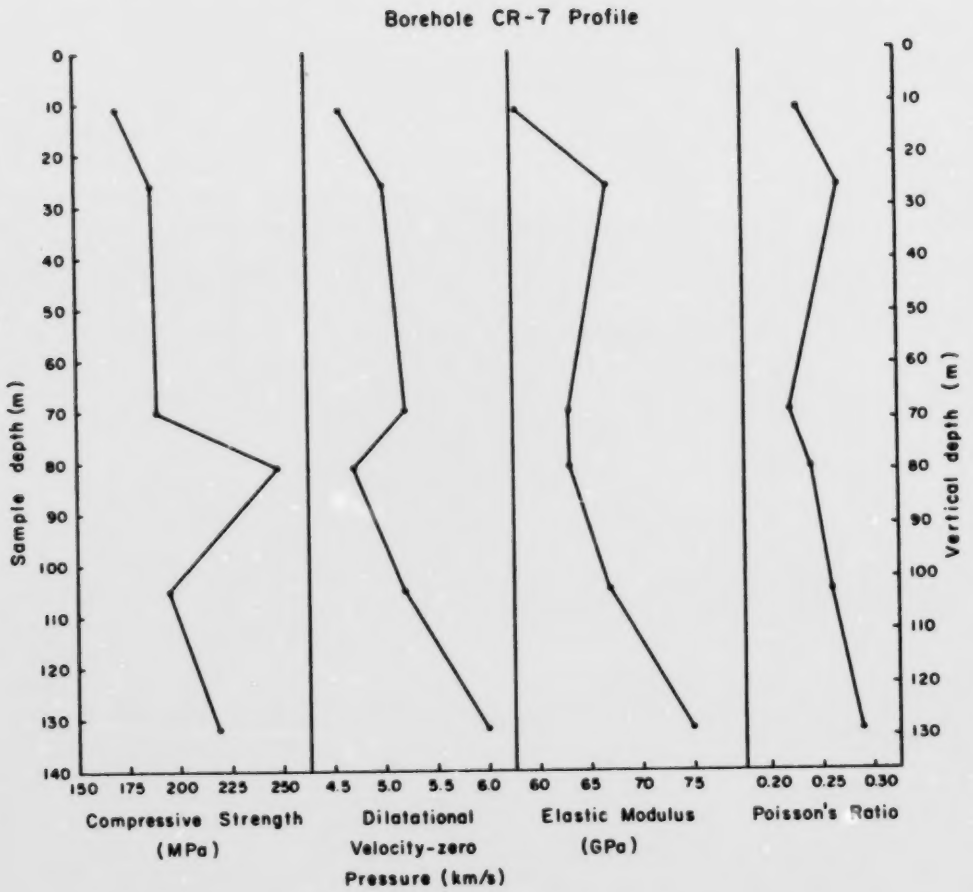


Fig. 3 - Uniaxial elastic properties and dilatational wave velocity profiles for borehole CR-7.

*Sample depth refers to the distance from the surface along borehole length.

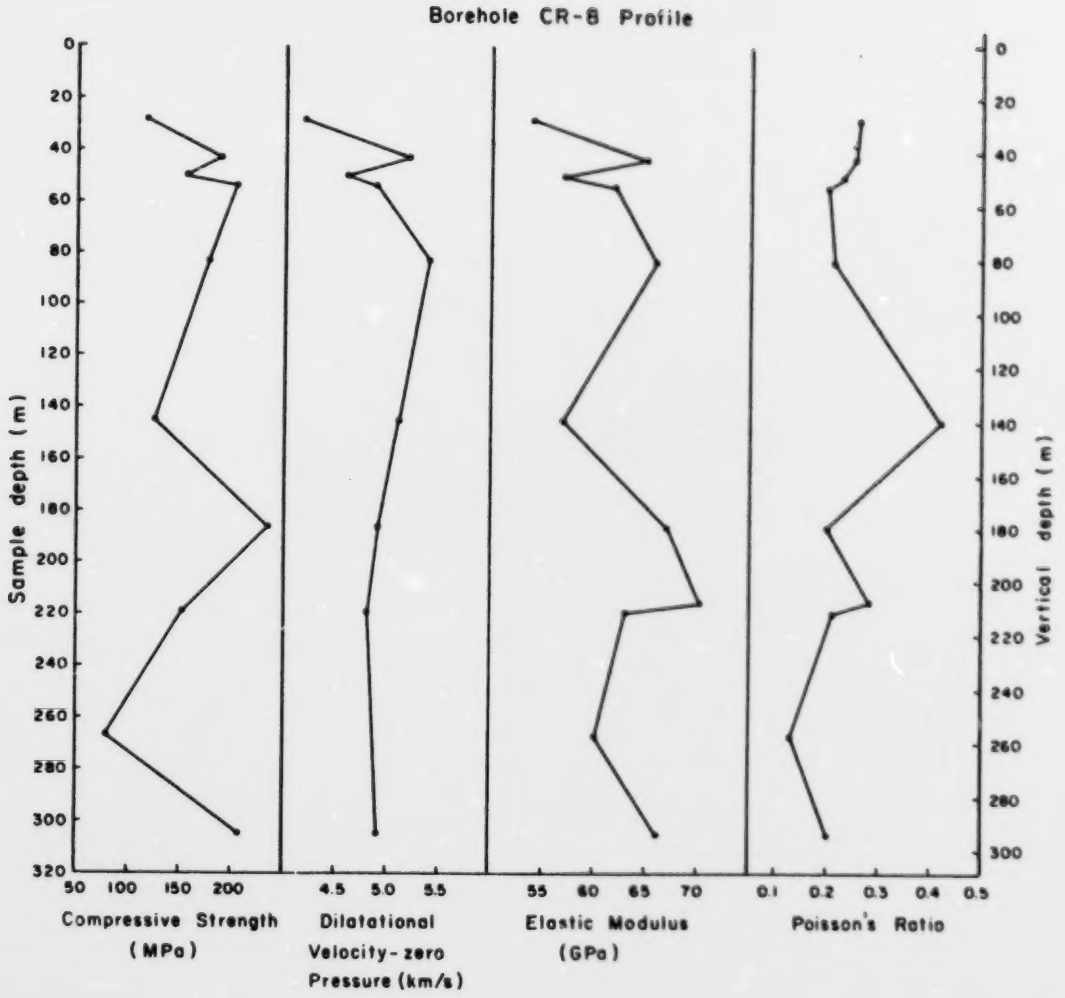


Fig. 4 - Uniaxial elastic properties and dilatational wave velocity profiles for borehole CR-8.

*Sample depth refers to the distance from the surface along borehole length.

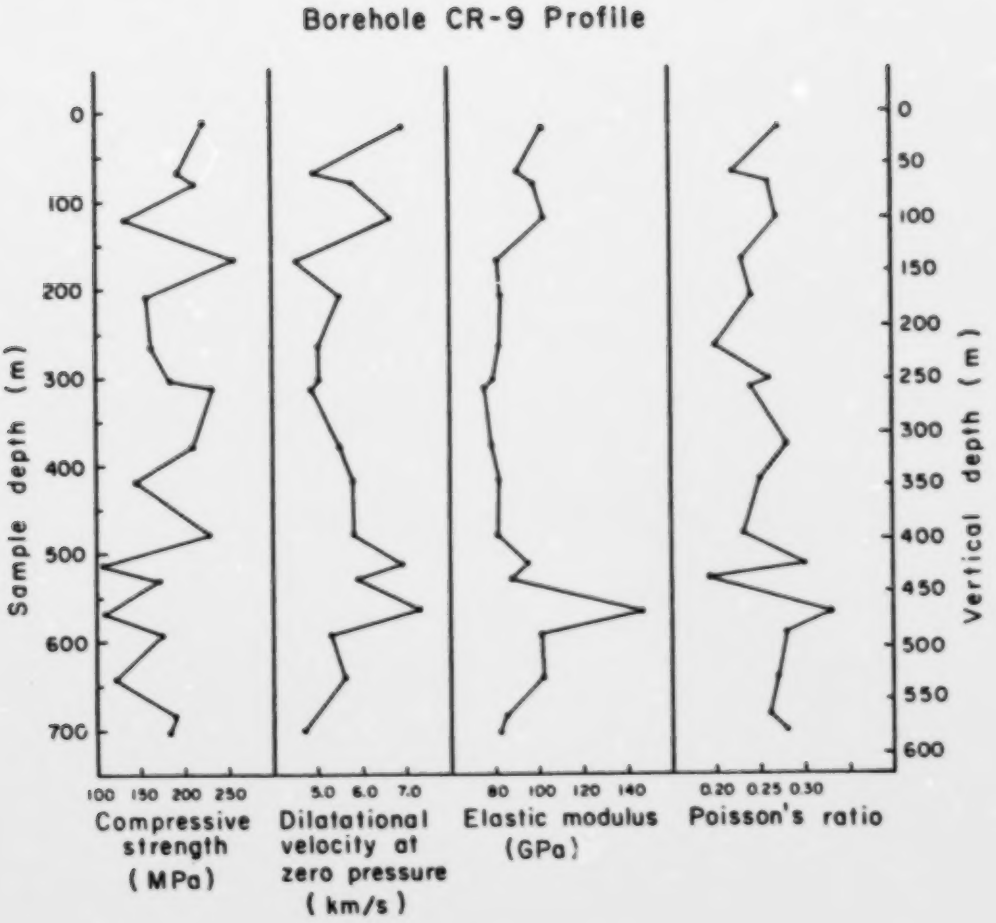
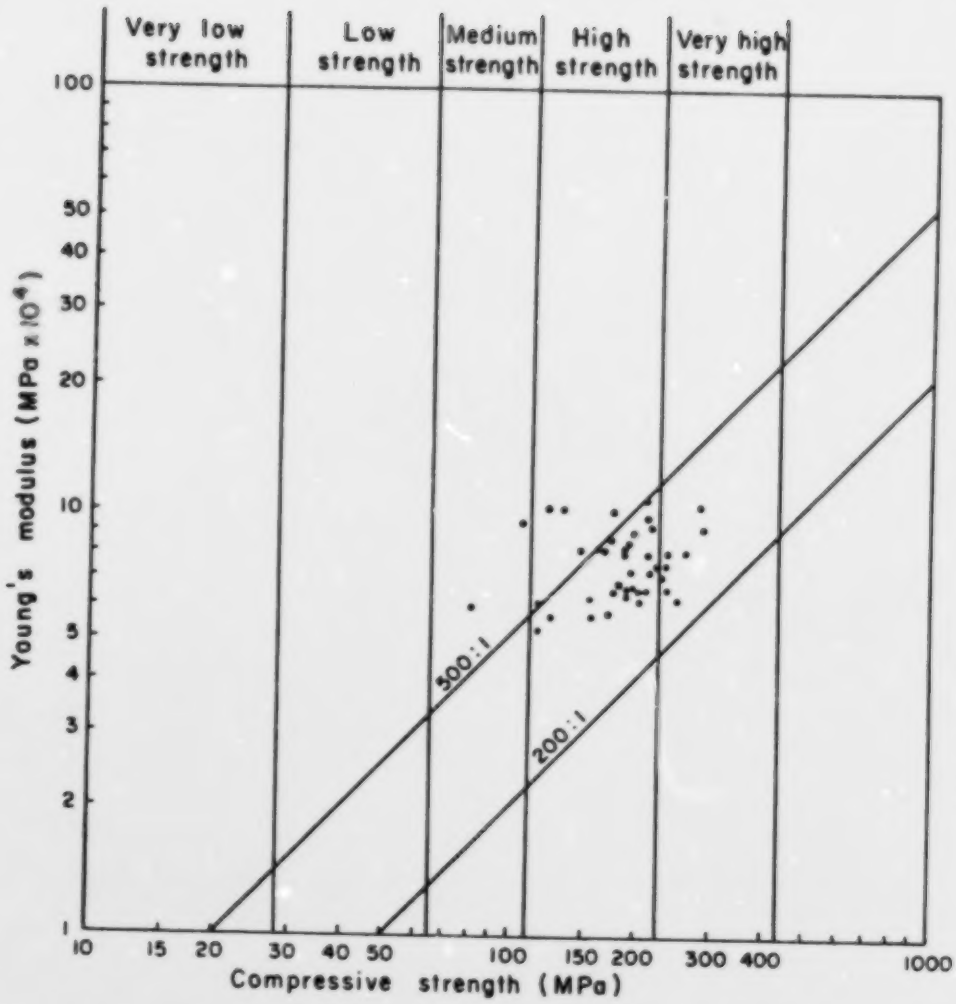


Fig. 5 - Uniaxial elastic properties and dilatational wave velocity profiles for borehole CR-9.

*Sample depth refers to the distance from the surface along borehole length.



Engineering classification for intact rock
(After Deere and Miller, 1966)

Fig. 6 - Engineering classification for intact rock (after Deere and Miller, 1966). Boreholes CR-6, CR-7, CR-8 and CR-9 specimens.

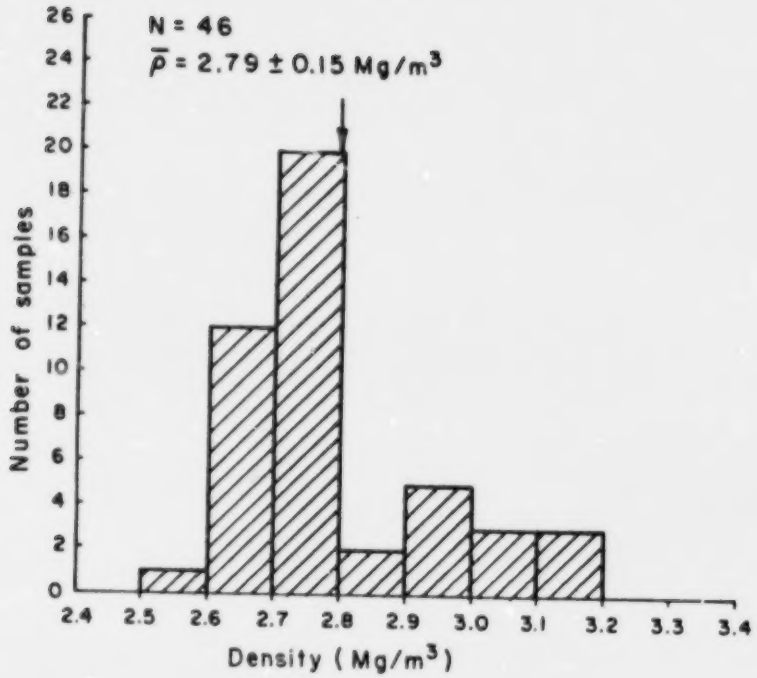


Fig. 7 - Histogram of density for CR-6, CR-7, CR-8 and CR-9 specimens.

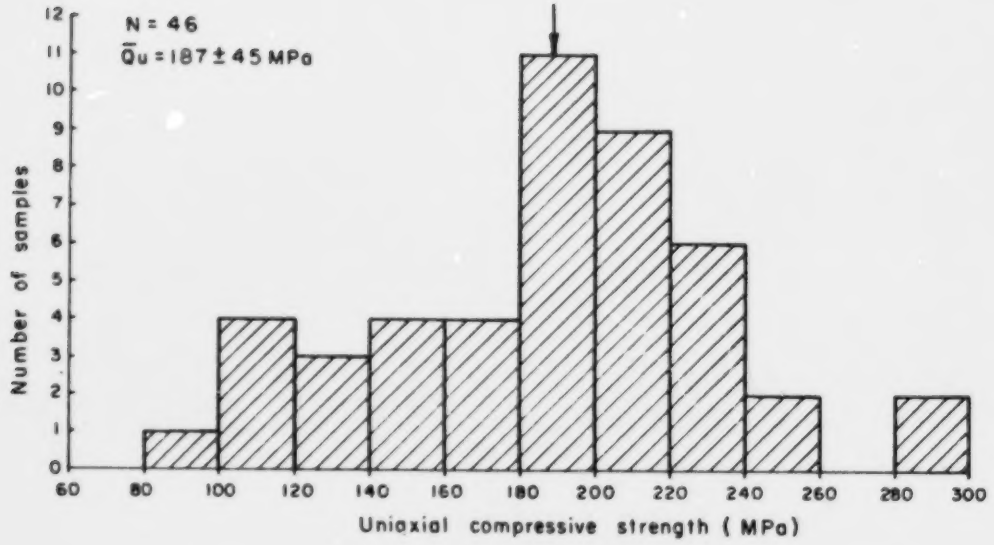


Fig. 8 - Histogram of uniaxial compressive strength for CR-6, CR-7, CR-8 and CR-9 specimens.

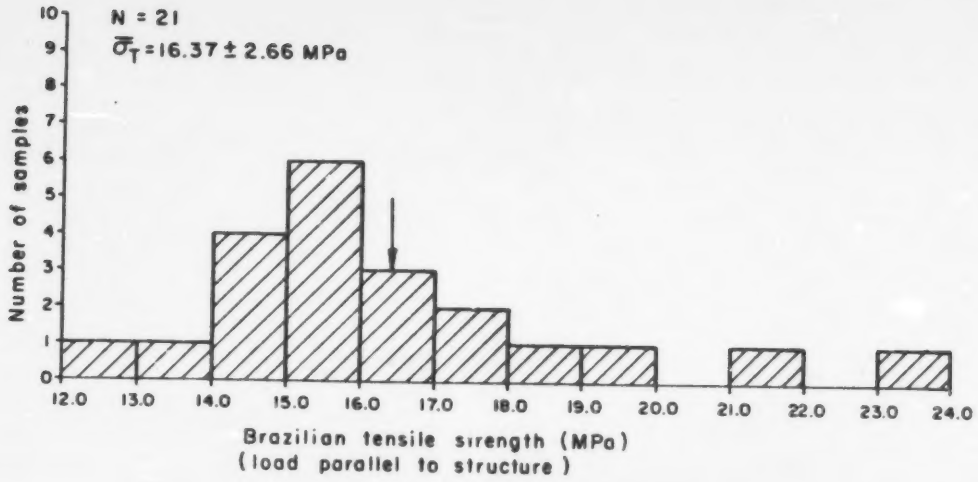


Fig. 9a - Histogram of Brazilian tensile strength for CR-8 and CR-9 specimens, (load applied parallel to structure).

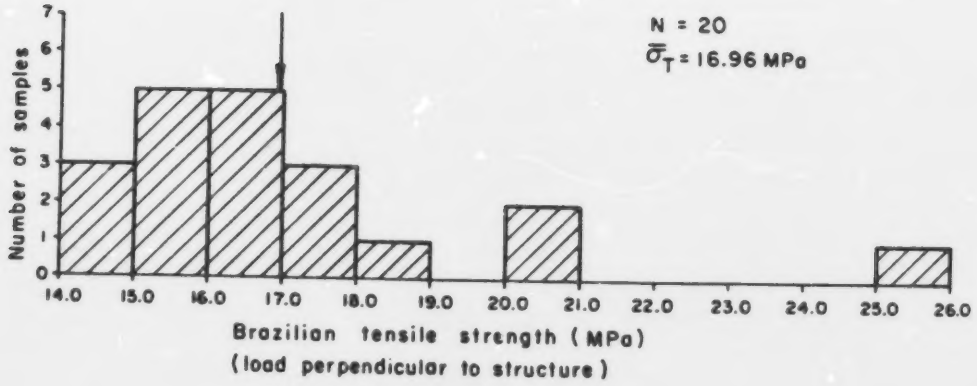


Fig. 9b - Histogram of Brazilian tensile strength for CR-8 and CR-9 specimens, (load applied perpendicular to structure).

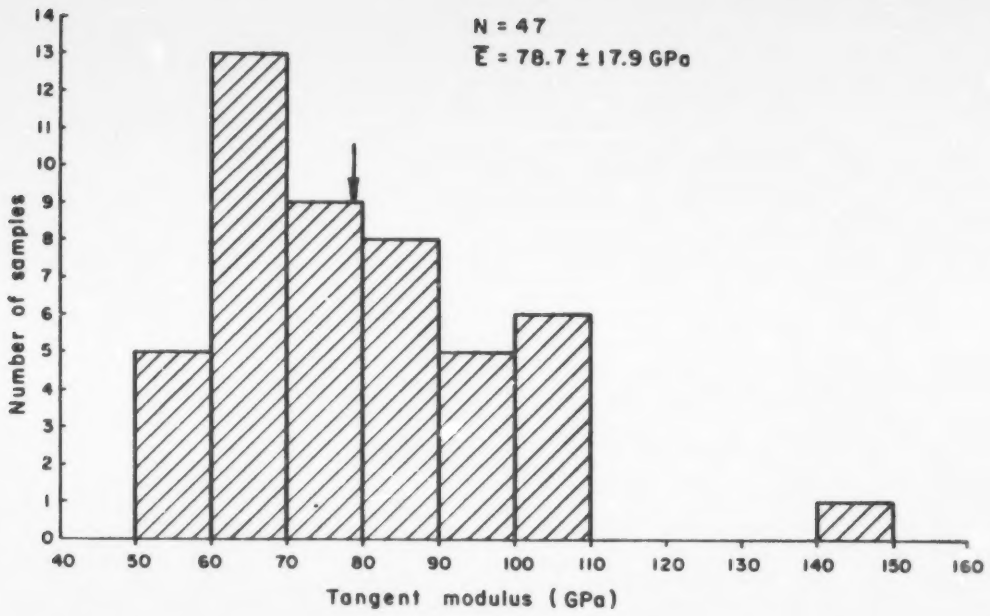


Fig. 10 - Histogram of Young's modulus for CR-6, CR-7, CR-8 and CR-9 specimens.

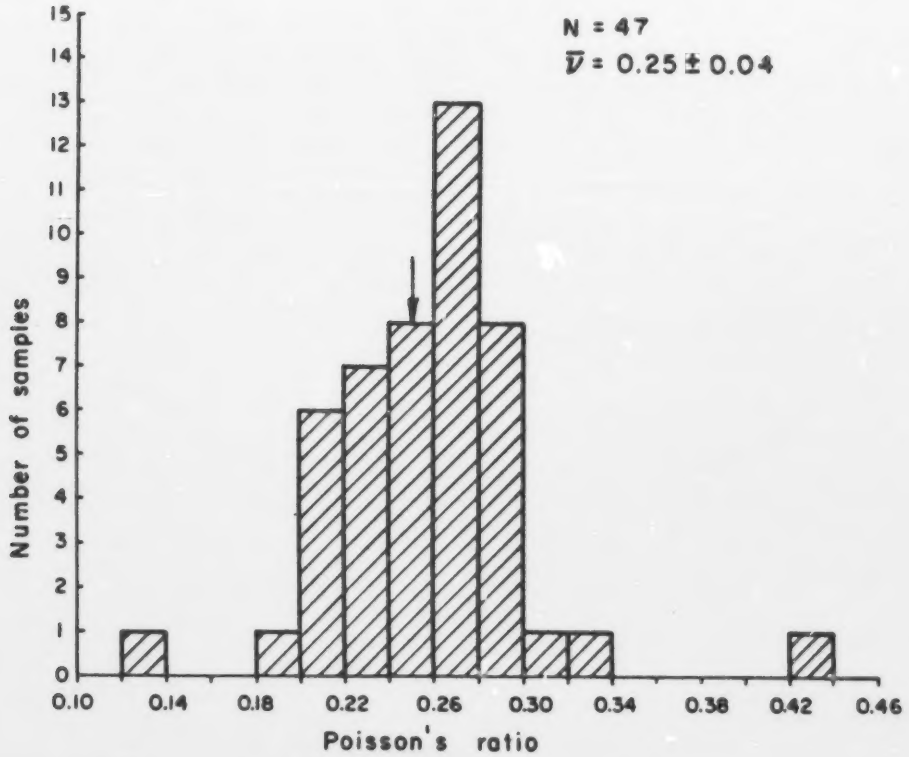


Fig. 11 - Histogram of Poisson's ratio for CR-6, CR-7, CR-8 and CR-9 specimens.

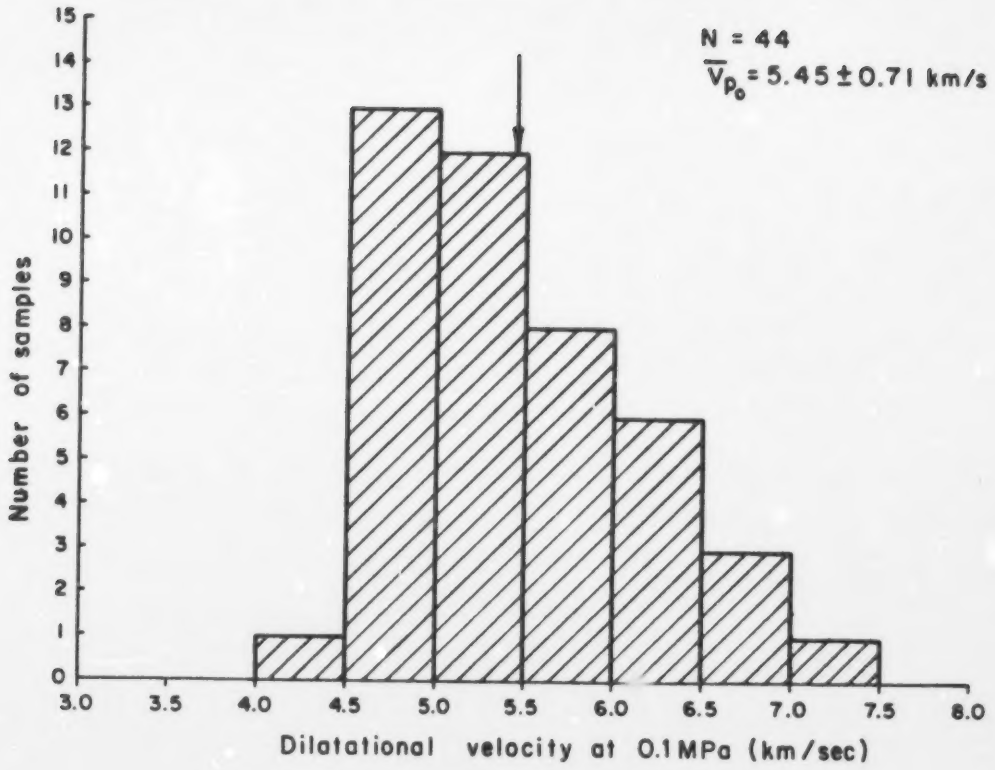


Fig. 12 - Histogram of zero pressure compressive wave velocity for CR-6, CR-7, CR-8 and CR-9 specimens.